

Resource Department

HYDROGEOLOGY

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The Hydrogeology Department (HD) consists of more than 50 scientists, postdocs, research associates, and graduate students carrying out a broad range of cutting-edge research in fundamental and applied hydrology. HD has expertise in theoretical, experimental, field, and modeling approaches in a variety of research areas, among which are unsaturated zone hydrology (including fracture flow and transport), reservoir engineering (including pore-level modeling and gas hydrate studies), contaminant hydrology (including reactive and colloid-assisted transport), and coupled nonisothermal, geochemical, and geomechanical processes. The HD addresses national needs in the areas of subsurface energy resource recovery, subsurface remediation, geologic CO₂ storage, and nuclear waste disposal. Highlights of research efforts in these areas over the last two years include the following:

SUBSURFACE ENERGY RESOURCE RECOVERY

Researchers in HD are studying ways to enhance production of energy from subsurface reservoirs containing methane gas hydrates, geothermal energy, and traditional oil and gas resources. In the area of methane hydrates, HD scientists are carrying out a sustained laboratory campaign to uncover fundamental properties of methane hydrates, such as dissociation kinetics and constitutive models, that can be incorporated into the world's leading methane hydrate simulator, TOUGH-Fx/Hydrate. This simulation code, developed by HD scientists, is now in public release, and several licenses have been purchased by international energy companies. A similarity solution for methane hydrate production has been developed for verifying the simulation capabilities in TOUGH-Fx/Hydrate. Continuing the long tradition of geothermal research in the ESD, staff members in HD are investigating reactive geochemistry in geothermal reservoirs to devise ways to avoid mineral scaling and maintain injectivity without inducing short-circuiting flow paths. This effort is undertaken using TOUGH-REACT, the reactive geochemical simulator developed by HD researchers.

HD staff also developed a version of TOUGH2 called T2CA to study the feasibility of detecting hidden geothermal systems through monitoring of CO₂ emissions in the shallow subsurface environment. In collaboration with researchers in the Geophysics Department, HD staff confirmed that viscous fluid flow creates anomalies at low seismic frequencies that can be used to image oil reservoirs. By this method, re-analysis of 3-D seismic data using frequency-dependent approaches has revealed hydrocarbon-rich layers where none were detected by standard analysis.

SUBSURFACE REMEDIATION

HD researchers address national and international needs for subsurface contaminant characterization and remediation across the spectrum of approaches. In the lab, HD researchers are investigating some of the nation's most critical subsurface contamination issues, including the chemical evolution of highly alkaline Hanford tank waste, reduction, re-oxidation, and diffusion of Uranium VI in sediments, hydraulic properties of unsaturated gravels, and the natural production of transport-enhancing mobile nanoparticles in the subsurface. In the field, HD investigators lead the Berkeley Lab site restoration effort to remediate groundwater plumes containing dissolved chlorinated solvent and fuel contaminants. The remediation plan developed over the last several years, on time and under budget estimates, has been approved by DOE, placing the LBNL site in position for an efficient and cost-effective remediation phase. Additional field studies include work at a nearby closed army base to analyze contaminant plume evolution and measure groundwater flow velocities using heat-based flow sensors. Advances in subsurface characterization are expected to follow from HD's work on joint hydrologic and geophysical inversion that exploits the iTOUGH2 inverse modeling code. Continued collaboration with scientists in other ESD departments and Berkeley Lab divisions is currently under way, with a focus on the coupled water-energy system in California. Finally, HD maintains an international program to develop and test advanced technologies at sites

worldwide, which can then be used domestically to help with our nation's most difficult contamination problems.

GEOLOGIC CO₂ STORAGE

HD researchers are involved in a wide range of efforts involving field pilot tests, laboratory work, simulation and modeling of coupled CO₂ flow and transport processes, and risk assessment. HD staff carry out experiment design, instrumentation, and field monitoring of geologic CO₂ storage pilot tests, as well as laboratory experiments of CO₂ flow behavior. In the area of field tests, HD staff performed exhaustive simulations in advance of the Frio CO₂ pilot injection to predict the resulting CO₂ migration. In a parallel effort for the Frio CO₂ injection pilot project, HD staff successfully developed, deployed, and operated a novel U-tube sampler for monitoring CO₂ and other fluids at the observation well. As for more general research in the modeling area, TOUGH-REACT has been used to study coupled flow and reactive geochemistry to evaluate the impacts of impurities in the injected CO₂ stream on mineral trapping of CO₂. New TOUGH2 modules are being used to evaluate complex phase-change and phase interference behavior that could arise during severe leakage events. HD scientists showed by simulation that even small CO₂ leakage fluxes can produce high CO₂ concentrations in the shallow subsurface environment. A screening and ranking framework was developed to prioritize candidate storage sites on the basis of CO₂ leakage risk. HD researchers will continue to be at the forefront in all aspects of this growing field.

NUCLEAR WASTE DISPOSAL IN THE UNSATURATED ZONE

The motivation for HD's extensive effort in unsaturated zone hydrology and coupled processes is stimulated by the need to understand flow and transport in the unsaturated zone at Yucca Mountain, Nevada, the site of the proposed nuclear waste repository. Research by HD scientists in this prominent area includes infiltration and seepage, coupled nonisothermal and geomechanical effects, and transport of radionuclides. Starting with research underground, HD scientists have found evidence for significant water vapor transport in closed-off tunnels at Yucca Mountain, with implications for natural-fracture vapor transport as the source of the water vapor. Field investigations at a natural analogue site in Mexico suggest that radionuclide transport is primarily in unsaturated fractures, just as predicted for Yucca Mountain. Field experiments have ranged from the large multi-year drift-scale heater test to smaller-scale liquid releases in boreholes. The practical

difficulties of running tests underground at a remote site have motivated the development of sophisticated remote monitoring and operation capabilities, whereby instrument adjustments, liquid releases, and data collection can be controlled remotely by scientists on site at Berkeley Lab. The coupled approach of field experiment and modeling analysis has served to advance understanding of the coupled flow and transport properties of Yucca Mountain. Field data are used to constrain and calibrate numerical models of flow and transport using the inverse modeling version of TOUGH2 called iTOUGH2, also developed by HD personnel. On the mountain scale, a large three-dimensional TOUGH2 model has been developed to evaluate mountain-scale thermal effects on multiphase flow. The details of seepage into drifts, flow diversion, and flow focusing are modeled on appropriate scales, as are processes of water-rock interaction and geomechanical effects. Work in the nuclear waste area also extends to saturated systems in Japan, where transient pressure data have been used to constrain a flow model in fractured granite.

A considerable amount of general unsaturated zone hydrology knowledge and understanding is generated by HD researchers. For example, new broadly applicable conceptualizations of fracture-matrix interaction and scale dependence of matrix diffusion have been investigated. Often models developed in one area find application in other areas. The large effort in HD on a broad range of hydrologic processes related to nuclear waste disposal typifies the strong integration of field, laboratory, and modeling analyses characteristic of ESD scientific investigations.

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